

PIOTR HULISZ^{1*}, WOJCIECH KWASOWSKI², JERZY PRACZ², RYSZARD MALINOWSKI³

¹Department of Soil Science and Landscape Management, Faculty of Earth Sciences, Nicolaus Copernicus University, Lwowska Str. 1, Toruń, Poland

²Division of Soil Sciences, Department of Soil Environment Sciences, Faculty of Agriculture and Biology, Warsaw University of Life Sciences – SGGW, Nowoursynowska Str. 159, 02-776, Warsaw, Poland

³Department of Soil Science, Grassland and Environmental Chemistry, Faculty of Environmental Management and Agriculture, West Pomeranian University of Technology, Słowackiego Str. 17, 71-424 Szczecin, Poland

Coastal acid sulphate soils in Poland: a review

Abstract: This paper presents the state of knowledge on coastal acid sulphate soils in Poland. The properties of these soils are closely related to the influence of brackish water from the Baltic Sea, high accumulation of organic matter and human activity. The obtained results demonstrate that the sulphide accumulation in soils refers to a relatively small areas of the Polish coastal zone with the unique and very valuable habitats. They require an adequate regulation of the water relations to avoid the risk of strong soil acidification and environmental pollution by heavy metals. Currently, there are no relevant criteria for classification of acid sulphate soil materials in the Polish Soil Classification (2011). Therefore, based on the presented data, the authors proposed to identify these features at the lower classification level (for different soil types). The criteria for the Thionic and Sulfidic qualifiers used in the WRB classification (IUSS Working Group WRB 2015) could be accepted for this purpose.

Keywords: acid sulphate soils, sulphide oxidation, soil acidification, Polish Soil Classification, Baltic Sea

INTRODUCTION

Acid sulphate soils (ASS) (in Polish: *gleby kwaśne siarczanowe*) is the common name given to soils rich in iron sulphides. They cover an area of 12–13 million ha in the world, with about 10 million ha in tropical regions. In Europe, the largest ASS occurrences are found in Finland (over 160 million ha) and Sweden (over 500 million ha) (Yli-Halla et al. 1999, Andriessse and Van Mensvoort 2006, Fältmarsch et al. 2008).

Acid sulphate soils develop in very specific geochemical conditions at significant contribution of microbiological processes. The formation of sulphide minerals, predominantly pyrite (FeS₂) or monosulphides (FeS) may occur in coastal, inland, and minespoil environments. Deposits of mudflats, mud tidal swamps, brackish lakes and also mine waste are usually the richest in these minerals (Dent and Pons 1995, Giani 1992, Fitzpatrick and Shand 2008, Fältmarsch et al. 2008, Uzarowicz and Skiba 2011). Depending on the oxidation-reduction conditions, two variants of ASS are distinguished. This subdivision is of practical application and refers to a group of soils with a variable origin and systematic position, representing a set of specific diagnostic features. Potential acid sulphate soils (PASS; in Polish: *gleby potencjalnie kwaśne siarczanowe*) represent waterlogged or unexcavated

soils containing a high content of pyrite. These soils are neutral or slightly acid in the field. When PASS are exposed to air or oxygen due to drainage, excavation or other anthropogenic transformations, sulphuric acid is produced. If the acid neutralizing capacity of the soil material is low, pH values may drop below 4.0. Such soils are defined as actual acid sulphate soils (AASS; in Polish: *gleby aktualnie kwaśne siarczanowe*) (Dent 1986, Langenhoff 1986).

In environments with unstable redox conditions, soils with both PASS and AASS properties may occur (Sammot et al. 1996). Due to the possible release and migration of toxic substances in a strongly acid environment (e.g. heavy metals), soil sulphatisation is treated as a serious hazard, with negative impact on valuable natural ecosystems and humans (Dent and Pons 1995, Wallin et al. 2015).

The accumulation of sulphides is a crucial process affecting the properties of soils in the Polish coastal zone along the Baltic Sea (Pracz 1989, Kwasowski 1999, Niedźwiecki et al. 2000, 2002; Hulisz 2013). Despite relatively good recognition, acid sulphate soils have not been distinguished in the Polish Soil Classification (2011). This report presents the state of knowledge on these soils. Based on the presented data, some suggestions are made to improve the Polish soil classification system.

DISTRIBUTION AND EXTENT OF ACID SULPHATE SOILS IN THE POLISH COASTAL ZONE

Acid sulphate soils are important components of ecosystems functioning at the land-sea boundary. The primary source of SO_4^{2-} ions in this zone are seawater (McBride 1994, Dent and Pons 1995). Typical settings of acid sulphate soils in Poland are coastal marsh landscapes (Hulisz 2013, 2016). They occupy small areas along a narrow belt of coastal lowlands (peatlands, small marsh depressions close to the water line, wet margins of coastal lakes and river deltas). These soils are under the influence of brackish seawater and groundwater (Pracz 1989, Kwasowski 1999, Hulisz 2013). Their origin is distinctly different than that of soils of the Finnish coastal zone, where uplifted sulphide-rich clay sediments were deposited during the Holocene (Littorina Sea), and then artificially drained or uncovered as a result of peat mining (Yli-Halla et al. 1999, Fältmarsch et al. 2008).

More than 20 sites with acid sulphate soils have been noted in Poland, e.g. in the vicinity of the Szczecin Lagoon – reverse delta of the Świna River (Wolin, Wicko, Przytór, Karsibór, Wrzosowo and Kopice), Kamień Lagoon (Międzywodzie, Żółcino, Dusin and Strzeżewo), Słowińskie Coast (Jezierzany, Dąbki, Łazy, Dźwirzyno, Korzystno, Rowy and Mrzeżyno), and Kashubian Lakeland (Jastrzębia Góra, Władysławowo, Puck, Rewa, Mrzeżyno, Beka, Moście Błota) (Fig. 1). The total area of coastal acid sulphate soils in Poland has not been determined yet. However, some papers (e.g. Niedźwiecki et al. 2002, Urbańska et al. 2012, Hulisz 2013) report the occurrence of marsh

soils with ASS properties in the Karsiborska Kępa island (about 315 ha). The area of the two other major complexes of organic acid sulphate soils in Mrzeżyno (100 ha) and Mrzeżyno (150 ha) has also been estimated (Kwasowski 1999).

Apart from these localities, weakly saline or non-saline soils of the coastal zone are also known, in which sulphide accumulation took place in conditions differing from present-day. They reveal properties typical for both AASS and PASS. Their classification is difficult because their total sulphur content and other analytical data remain unknown. A decrease in pH (determined after drying soil samples in laboratory conditions) with depth has been observed in these soils. They include e.g. dewatered soils of the Vistula River Delta (Żuławy Wiślane), described by Baranowski (1962) and Witek (1965). The process of sulphide oxidation was best observed in heavy mud soils. A similar case occurred in peat-muck soils in the Słowiński National Park, in which the lowest pH values determined in horizons affected by groundwater were below 3 (Mocek 1978).

Moreover, properties similar to PASS and AASS were recorded in naturally salt-affected inland soils from the Kuyavian region, the Warta River valley and Nida River Basin (Czerwiński 1996, Hulisz and Piernik 2008), ameliorated floodplain soils of the mouth of the Warta River and the lower Oder River valley (Malinowski et al. 2004, Malinowski 2012), and in some technogenic soils developed from the bottom sediments of the Szczecin Lagoon (Piszczyk et al. 1961), the Vistula River delta (Hulisz et al. 2015), and minespoil materials (Hulisz et al. 2007, Uzarewicz and Skiba 2011, 2013).

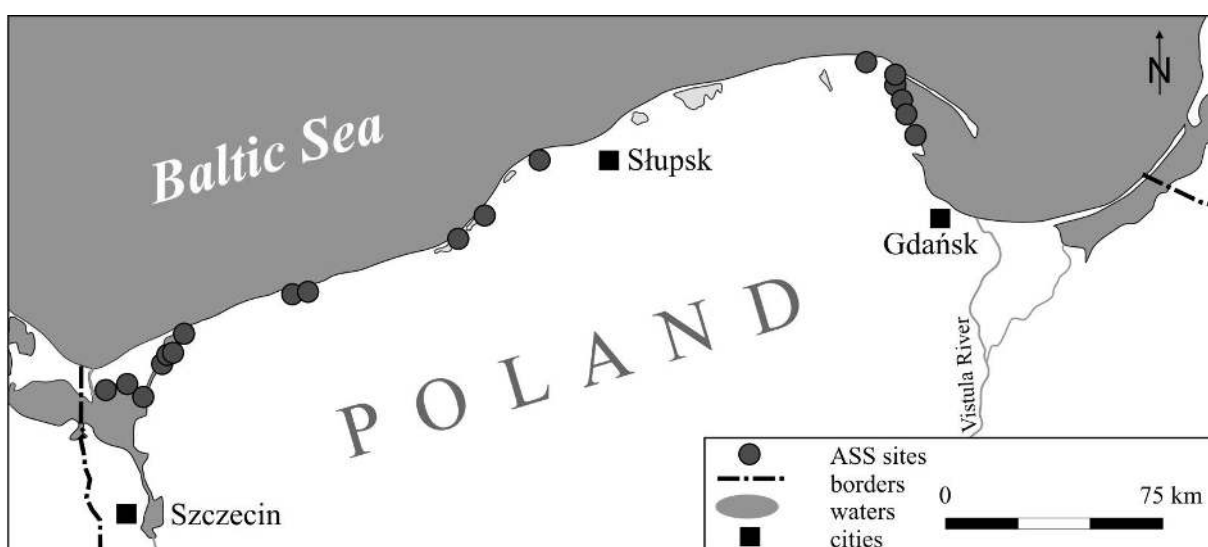


FIGURE 1. Distribution of coastal acid sulphate soils in Poland. Sources: Pracz (1989), Kwasowski (1999), Niedźwiecki et al. (2000), Pracz and Kwasowski (2001a,b), Pracz and Kwasowski (2006), Hulisz (2013)

PROPERTIES OF POLISH ACID SULPHATE SOILS

Studies conducted by the authors (Pracz 1989, Kwasowski 1999, Hulisz 2013) have indicated that PASS predominate across the acid sulphate soils in Poland. Due to the high susceptibility to acidification, these soils require a special methodological approach. One of such solutions may be a procedure proposed by Urbańska et al. (2012), which comprises both field and laboratory works (Fig. 2). It is based on the commonly applied methodology of investigations for PASS (Bloomfield and Coulter 1973, Dent 1986, Langenhoff 1986), but takes into account also the specific features of Polish soils. Thus, erroneous interpretations of the properties can be excluded, which largely depend on the dynamics of sulphur compounds such as pH, carbonate and sulphate content. Changes in these properties may be the result of potential sample acidification during drying in laboratory conditions.

Table 1 presents selected properties of coastal acid sulphate soils (a total of 48 soil profiles). They were developed both from organic (peat, muck, mud) and mineral sediments (sand and silt), deposited mainly in terrestrial-marine environments (Fig. 3 and 4). This is reflected in the very variable total organic content (TOC 0.1–42.2%) and total sulphur ($S_t < 0.1$ –7.0%). A low C:S ratio, reaching minimal values below 5, suggested the presence of mineral forms of sulphur (sulphides and sulphates). The influence of brackish waters of the Baltic Sea on the properties of the analysed

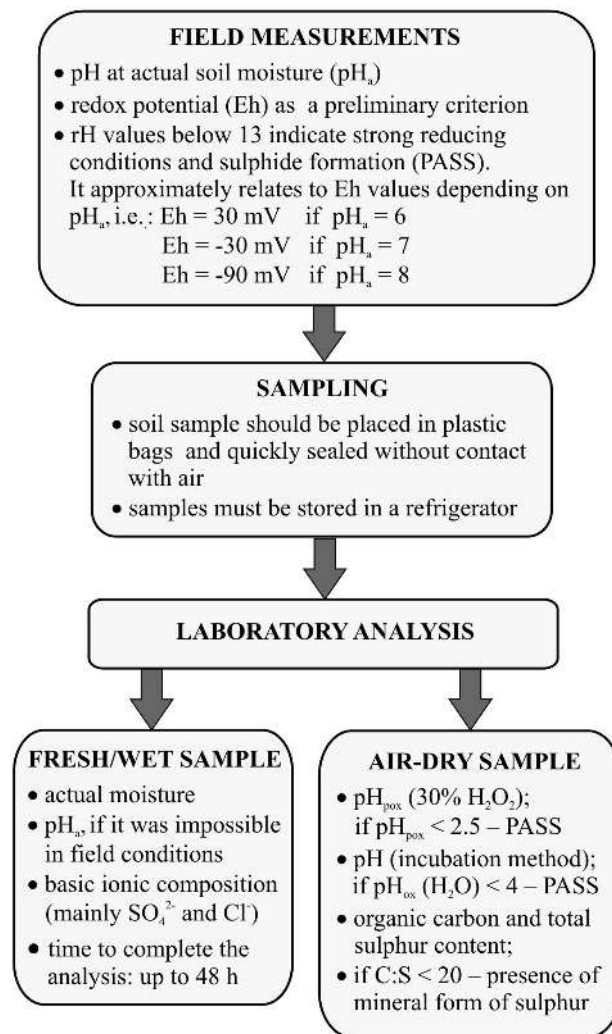


FIGURE 2. Proposed methodological procedure in the studies of PASS (Urbańska et al. 2012, modified)

TABLE 1. Selected properties of acid sulphate soils in Poland

Sites (number of soil profiles)	pH_a	pH_{ox}	pH_{pox}	TOC [%]	S_t	SO_4^{2-}	C:S	EC_e $dS \cdot m^{-1}$	Source
Wicko, Przytor (2)	4.0–7.1	2.5–5.8	1.1–4.6 ^c	1.8–36.4	0.7–5.4	0.14–3.29 ^a	2–16	2.0–15.5	Pracz (1989)
Jezierzany, Dąbki Łazy (3)	5.3–7.3	2.7–7.3*	1.1–7.3 ^c	0.7–23.2	0.1–2.2	0.04–2.04 ^a	2–24	1.4–6.0	
Mrzezino (13)	3.1–6.0	2.2–5.7	1.7–4.3 ^c	2.9–40.6	0.2–3.6	0.02–2.96 ^a	8–59	0.5–5.8	Kwasowski (1999)
Mrzeżyno, Roby (12)	2.5–7.0	1.9–4.7	n.d.	7.8–42.2	0.2–7.0	0.01–8.72 ^a	3–56	0.5–27.3	Pracz and Kwasowski (2001a, b)
Moście Błota (6)	4.3–6.5	3.2–6.0	n.d.	1.6–41.7	0.2–3.1	0.01–2.18 ^a	7–64	0.4–6.0	Pracz and Kwasowski (2006)
Karsibór (4)	5.5–7.6	3.1–6.8	1.1–4.8	0.1–34.5	<0.1–2.8	0.01–0.30 ^b	2–70	4.0–14.6	Urbańska et al. (2012), Hulisz (2013)
Wrzosowo (2)	6.0–6.6	3.3–6.3	1.3–4.7	0.2–22.4	0.1–1.7	0.05–0.51 ^b	1–37	4.6–8.9	
Władysławowo (3)	6.0–7.4	3.9–7.4**	1.5–4.8	0.1–33.9	<0.1–1.6	0.01–0.49 ^b	7–53	2.2–16.5	
Chrzęszczewo (3)	5.7–7.3	4.1–7.5***	1.6–5.1	0.7–21.8	<0.1–4.8	0.03–0.63 ^b	4–85	3.7–17.1	Hulisz, unpublished

Explanations of symbols: pH_a – pH measurement referred to the actual soil moisture, pH_{ox} – pH measurement after sample air-drying under laboratory conditions, pH_{pox} – pH measurement after oxidation with 30% H_2O_2 , TOC – total organic carbon, S_t – total sulphur, SO_4^{2-} – ions content determined in the 1:5/1:10 soil-water extract, EC_e – electrical conductivity of the saturated paste extract.

*18.1–21.5% $CaCO_3$; **0.0–2.1% $CaCO_3$; ***0.0–1.1% $CaCO_3$; ^a air-dried sample; ^b fresh/moist sample; ^c sample oxidation with 3% H_2O_2 ; n.d. – not determined

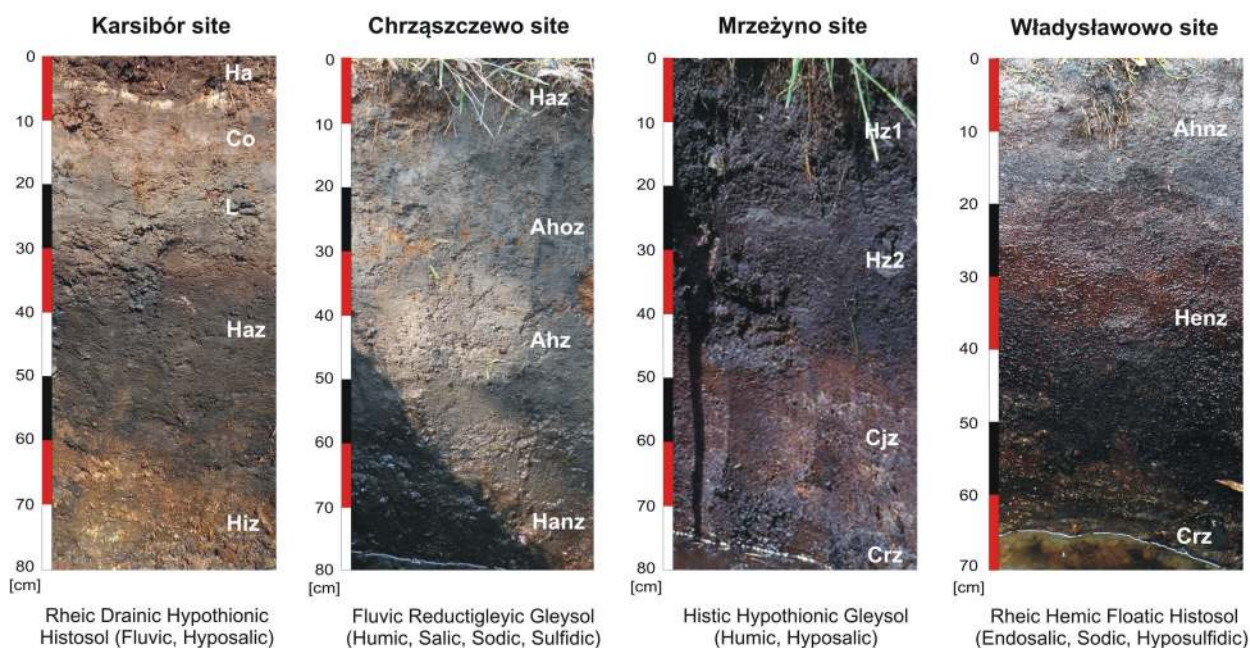


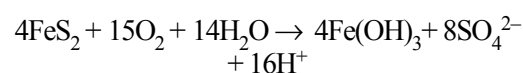
FIGURE 3. Morphology of selected Polish acid sulphate soils and their systematic position according to the WRB classification (IUSS Working Group WRB 2015). Symbols of soil horizons according to the Guidelines for Soil Description (2006)

soils was very clear. The electrical conductivity values of saturated paste extract (EC_e) were from 0.4 to $27.3 \text{ dS}\cdot\text{m}^{-1}$ (Table 1). The content of SO_4^{2-} ions which are one of the major components of seawater,

varied from 0.01 to 8.72%. The highest values were usually recorded in organic soils.

The presence of PASS in the discussed group of soils was evidenced mainly by large differences between pH measured in various conditions: at actual

soil moisture, in field conditions (pH_a), after sample air-drying under the laboratory conditions (pH_{ox}), and after oxidation with 30% (or 3%) peroxide solution (Table 1, Fig. 4). Strong acidification of the samples ($\text{pH}_{ox} < 4$; $\text{pH}_{pox} < 2.5$) was favoured by an almost complete lack of carbonates. The highest values of $\text{pH}_a - \text{pH}_{ox}$ and $\text{pH}_a - \text{pH}_{pox}$ were typically noted in soil horizons directly contacting with shallow groundwater. The maximal differences may reach up to 3 and 4 pH units, respectively (Fig. 4). The process of sulphide oxidation in the analysed soil is microbially and chemically induced. The most important product of the reaction is sulphate acid (VI), which is formed according to the following simplified formula (Dent 1986):



The acid may be neutralized in the case when the soil contains a sufficient contribution of CaCO_3 , or other components, such as alkaline cations or clay minerals, influencing the buffer capacity of the soil. It sho-

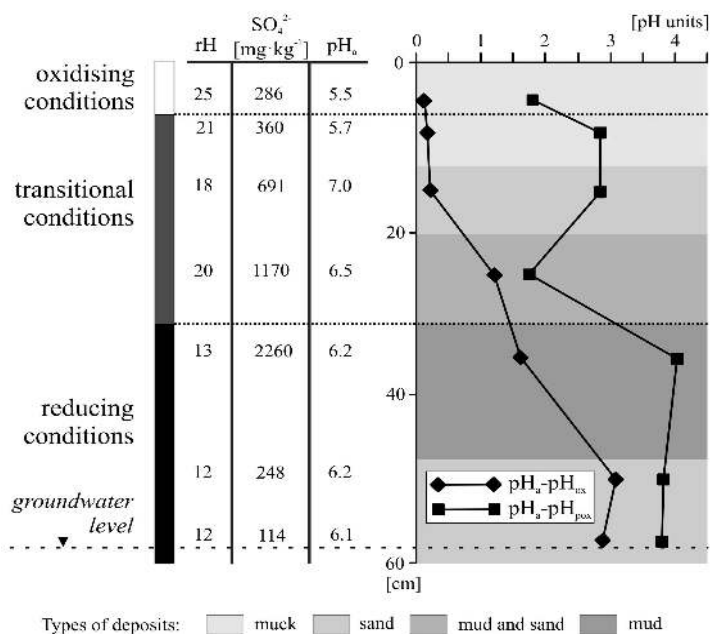
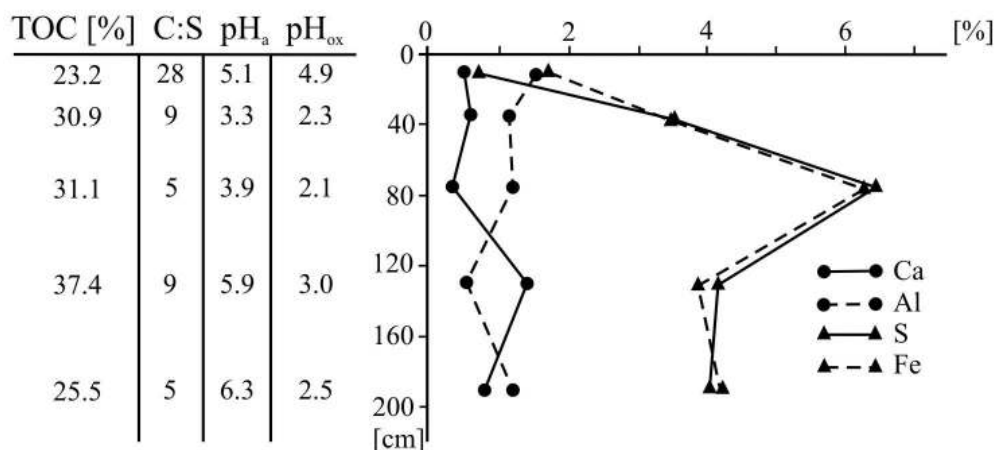


FIGURE 4. Profile distribution of differences in pH values measured at actual soil moisture (pH_a), after sample air-drying under laboratory conditions (pH_{ox}), and after oxidation with 30% H_2O_2 (pH_{pox}), in relation to other PASS properties (non-carbonate, saline soil; Karsiborska Kępa; Hulisz 2013) Explanations: rH – negative logarithm of the hydrogen partial pressure calculated from pH_a and Eh values (Guidelines for Soil Description 2006), SO_4^{2-} – ions content determined in the wet/fresh samples (1:5 soil-water extract).

FIGURE 5. Selected elements distribution in relation to other acid sulphate soil properties (Roby; Prac 1989)



uld be emphasized, however, that the process of sulphide oxidation and the proceeding acidification takes place in mineral horizons much faster than in the organic horizons, which have higher buffer capacity (Urbańska et al. 2012).

Organic acid sulphate soils examined by Prac (1989) have shown a clear relationship between the profile distribution of total sulphur and iron. As shown in Figure 5, partial disintegration of iron sulphides in the oxidation zone (20–80 cm) was observed (AASS material). It was confirmed by very low pH_a, pH_{ox} and the highest S and Fe content (even more than 6%). The content of calcium and aluminium was not dependent on the redox conditions and the sulphur content (Fig. 5).

ENVIRONMENTAL IMPACT OF ACID SULPHATE SOILS

Intense leaching of metals takes place during dehydration of soils rich in sulphide minerals and poor in carbonates. Some elements, such as aluminium, cobalt, nickel, zinc, cadmium or manganese usually occur in acid sulphate soils in amounts typical for non-contaminated soils. However, they are largely connected with sulphides, whose intense oxidation in conditions of strong acidification significantly increases their mobility (Sohlenius and Öborn 2004). As a consequence, particularly during heavy rainfall, they can be excessively concentrated in the nearby water courses (Smith and Melville 2004, Roos and Öström 2005, Österholm et al. 2005). For example, as estimated by Fältmarsch et al. (2008), the amounts of these metals introduced into water by washing out of acid sulphate soils are from 10 to 100 times larger than the amounts supplied by sewage from the entire industry of Finland.

Many reports about the environmental effects of metal release caused by dehydration and oxidation

of sulphide sediments in acid sulphate soils point to their significant impact on plants, animals and humans. They are excessively accumulated in tissues and affect ionic balance. Excessive concentrations of manganese, cobalt aluminium and nickel have been noted in oat grains cultivated on dehydrated acid sulphate soils. Similar results were noted in grass from green areas (Palko 1986, Yli-Halla and Palko 1987). Analysis of the contribution of heavy metals in the milk of cows fed by fodder from areas covered by acid sulphate soils has indicated elevated contributions of iron and zinc, whereas the concentration of aluminium in milk of cows grazing in these areas was up to 50 times higher in relation to the reference material (Alhonen et al. 1997). In Poland, there are only a few studies on the environmental effects of acid mine drainage and metal release from acid sulphate soils (e.g. Wołowski et al. 2013). In this context it is particularly important to analyse both the contributions and forms of all potentially toxic metals derived from these soils, as well as conduct interdisciplinary research assessing their accumulation in subsequent links of the trophic chain.

Acid sulphate soils in Poland are an integral part of habitats with halophytes, which are subject to protection under the auspices of the Natura 2000 network (Herbich 2004). The functioning of these habitats strictly depends on the inflow of saline water and requires proper land management. The largest hazards are posed by drainage and construction of embankments. An example of soils most susceptible to changes of water balance are PASS occurring in the Karsiborska Kępa (Hulisz 2013). The area of this island is influenced by waters of the Stara Świna River supplying alluvial material and brackish waters from the Baltic Sea rich in sulphates. Soil sulphatization is also favoured by the formation of marshes, which are the effect of hydrotechnical activities carried out in the previous century (Niedźwiecki et al. 2002, Hulisz

2013). It should be expected that artificial drainage of the island would lead to decrease of the groundwater level, which in turn would cause strong acidification of soils due to oxidation of sulphur compounds within them (Czyż et al. 2010, Urbańska et al. 2012). Such situation is currently observed in the human-transformed floodplain soils of the mouth of the Warta River and the lower Oder River valley. There are non-saline soils developed from muds and mineral sediments rich in organic matter. The specific features of these soils are strong acidification and high amount of the iron and sulphur (Malinowski et al. 2004, Malinowski 2012).

SUGGESTIONS FOR THE CLASSIFICATION OF ACID SULPHATE SOILS IN POLAND

Distinguishing the above described variants of acid sulphate soils is important for diagnosing particular environmental hazards and sustainable use. On the other hand, the process of sulphide accumulation (excluding technogenic soils of landfills), similarly as salinization is clearly linked to the gleyic process, and it is obviously of secondary significance in relation to the genesis of the analysed soils (Pracz 1989, Hulisz 2007, 2013, 2016).

As evidenced by the author's investigations (Table 1), various types of coastal soils in Poland may be characterized by acid sulphate soil properties. Among them dominate soils fulfilling the criteria of the Polish Soil Classification (2011) for organic soils (in Polish: *gleby organiczne*) and gleysols (in Polish: *gleby glejo-*

we) (Fig. 3). Unfortunately, due to the lack of relevant criteria, a full systematic description of acid sulphate soils is not possible. According to the WRB classification (IUSS Working Group WRB 2015), properties of PASS and AASS may be described by using (Hypo)Sulfidic and (Hypo)Thionic qualifiers. For example, the pedons of acid sulphate soils have been classified as: Drainic Hypothionic Histosol (Fluvic, Protosalic), Fluvic Reductigleyic Gleysol (Salic, Sodic, Sulfidic), Histic Hypothionic Gleysol (Protosalic) and Hemic Floatic Histosol (Endosalic, Sodic, Hyposulfidic) (Fig. 3). The obtained results reflect the formation of such soils in various environmental conditions.

Acid sulphate soil formation in coastal areas is associated with both geogenetic and pedogenetic processes – geo-pedogenesis (Giani 1992). Brümmer (1968) considered the reduction of Fe, Mn and S as a component of geogenetic processes and the oxidation of these elements as a process strictly related to pedogenesis. The similar approach was taken into account when creating the criteria in the WRB classification (IUSS Working Group WRB 2015). The taxonomic rank of AASS and PASS features is different. The *thionic* horizon and *sulfidic* materials are used as diagnostic criteria. Consequently, Thionic (AASS) is principal qualifier while Sulfidic (PASS) is supplementary one.

As shown in Table 2, many investigated coastal soils meet the criteria for *thionic* horizon and/or *sulfidic* materials used in the WRB classification (IUSS Working Group WRB 2015). In light of this fact, it seems to be appropriate to introduce two new diagnostics to the next edition of Polish Soil Classi-

TABLE 2. Number of analysed soil profiles that meet criteria using for *Thionic* horizon and *Sulfidic* materials (IUSS Working Group WRB 2015) within 100 cm from the surface

Sites	Number of profiles	SO ₄ ²⁻ ≥0.05%*	Inorganic sulphidic S ≥0.01%	pH _a ≥4.0	pH _{ox} <4.0	pH _{ox} ≥2.5	Source
Wicko, Przytor	2	2	2	2	2	2	Pracz (1989)
Jezierzany, Dąbki, Łazy	3	3	3	3	2	3	
Mrzezino	13	12	13	13	13	n.d.	Kwasowski (1999)
Mrzezyno-Roby	12	12	12	6	12	n.d.	Pracz and Kwasowski (2001a,b)
Moście Błota	6	5	6	6	6	n.d.	Pracz and Kwasowski (2006)
Karsibór	4	2	4	4	3	4	Urbańska et al. (2012), Hulisz (2013)
Wrzosowo	2	2	2	2	2	2	
Władysławowo	3	1	3	3	1	1	
Chrzęszczewo	3	3	3	3	0	3	Hulisz, unpublished
In total	48	42	48	42	41	15	

Explanations of symbols: SO₄²⁻ – ions content (% by mass) determined in the 1:5/1:10 soil-water extract, pH_a – pH measurement referred to the actual soil moisture, pH_{ox} – pH measurement after sample air-drying under laboratory conditions, pH_{pox} – pH measurement after oxidation with 30% H₂O₂. * thickness ≥15 cm; n.d. – not determined.

fication: *sulfatic* properties (AASS) and *sulfidic* material (PASS). The detailed definition of these diagnostics requires further discussion. Their taxonomic rank and criteria could be referred to the WRB system, taking into account soil conditions in Poland. It is difficult to specify how the hierarchical structure of the Polish Soil Classification will change in the future. However, there is no doubt that both acid sulphate soils features should be described at the lower classification level. In author's opinion, the suggested solution is universal in character and could be used in qualifying other soils with PASS and AASS properties that occur in inland areas or are subjected to anthropogenic (technogenic) activity. Similar proposals have been earlier developed by Prac (1989) and Hulisz (2013, 2016). The first one concerned organic soils and gleysols, and the second – coastal marsh soils.

SUMMARY

Salt-affected soils along the Polish coast may contain significant amounts of mineral forms of sulphur (sulphides and sulphates). The specific properties of these soils result from the influence of brackish water from the Baltic Sea, high accumulation of organic matter and human impact. Due to the susceptibility to strong acidification caused by iron sulphide oxidation, potential acid sulphate soils (PASS) require a specific analytical approach both in field and laboratory investigations.

The presented data indicate that the problem of sulphur accumulation refers to a relatively small area of coastal soils. However, they are an important component of unique habitats with very high ecological value and require special measures during their management, such as regulating and raising water levels to keep acid sulphate soils saturated. If such measures are not met with, then there is a large risk of strong soil acidification, and soil and water pollution by heavy metals. Therefore, further studies of such soils with regard to potential environmental hazards are indispensable.

According to the results obtained by the authors of this paper, processes of AASS and PASS formation should be considered as a secondary in relation to other previously or simultaneously occurring soil-forming processes. This is evidenced by the morphology of the studied soils, corresponding to the primarily developed types (especially organic soils and gleysols). Therefore, distinguishing the AASS and PASS features (*sulphatic* properties and *sulphidic* material) at the lower level of the next edition of Polish Soil Classification would be justified. This suggestion would refer not only to soils occurring in the coastal zone but

also to some variants of inland salt-affected soils and technogenic soils. In the author's opinion, for the identification of AASS and PASS features in Polish soils, the criteria used in the WRB classification (Thionic and Sulfidic qualifiers; IUSS Working Group WRB 2015) could be accepted.

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Kwaśne gleby siarczanowe w polskiej strefie brzegowej

Streszczenie: Wśród zasolonych gleb polskiej strefy brzegowej zawierających znaczne ilości mineralnych form siarki dominują gleby potencjalnie kwaśne siarczanowe (PASS). Są to gleby, które swoje właściwości zawdzięczają przede wszystkim oddziaływaniu słonych wód Morza Bałtyckiego, znacznej akumulacji materii organicznej, a także wpływowi człowieka. Ze względu na podatność na silne zakwaszenie spowodowane utlenianiem siarczków żelaza wymagają one specyficznego podejścia badawczego zarówno w badaniach terenowych, jak i w laboratorium. Prezentowane dane wskazują, że problem zasiarczenia dotyczy relatywnie małego arealu gleb nadmorskich. Są one jednak istotnym składnikiem unikatowych siedlisk o bardzo wysokiej wartości ekologicznej i wymagają specjalnych zabiegów w czasie użytkowania, z których do najważniejszych należy utrzymanie odpowiedniego poziomu wód gruntowych. W przeciwnym razie istnieje duże ryzyko bardzo silnego zakwaszenia oraz zanieczyszczenia pierwiastkami śladowymi gleb i wód. W związku z tym konieczne są dalsze szczegółowe badania tych gleb pod kątem potencjalnych zagrożeń środowiska. Zgodnie z wynikami uzyskanymi przez autorów, procesy akumulacji utleniania siarczków powinny być traktowane jako procesy towarzyszące innym procesom glebotwórczym. Wskazuje na to przede wszystkim morfologia badanych gleb, odpowiadająca pierwotnie ukształtowanym typom (szczególnie glebom organicznym i glejowym). W związku z tym miałyby uzasadnienie wyróżnianie cech zasiarczenia przy różnych jednostkach glebowych na niższym poziomie klasyfikacji, tj. podtypie, odmianie – w zależności od struktury nowej wersji Systematyce gleb Polski. Dla prawidłowej identyfikacji tych cech, po uwzględnieniu ich rangi taksonomicznej, zaproponowano wprowadzenie właściwości *sulfat* (AASS) i materiału *sulfid* (PASS). Sugestia ta dotyczyłaby nie tylko gleb występujących w strefie nadmorskiej, ale także pewnych wariantów śródładowych gleb zasolonych oraz technogenicznych. Zdaniem autorów, w tym celu można by przyjąć definicje dla kwalifikatorów Thionic and Sulfidic, stosowanych w klasyfikacji WRB (IUSS Working Group WRB 2015).

Słowa kluczowe: kwaśne gleby siarczanowe, utlenianie siarczków, zakwaszenie gleb, Systematyka gleb Polski, Morze Bałtyckie